

## **Efforts by the Nuclear Industry to Evaluate Check Valve Failures**

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# EFFORTS BY THE NUCLEAR INDUSTRY TO EVALUATE CHECK VALVE FAILURES

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## I. INTRODUCTION

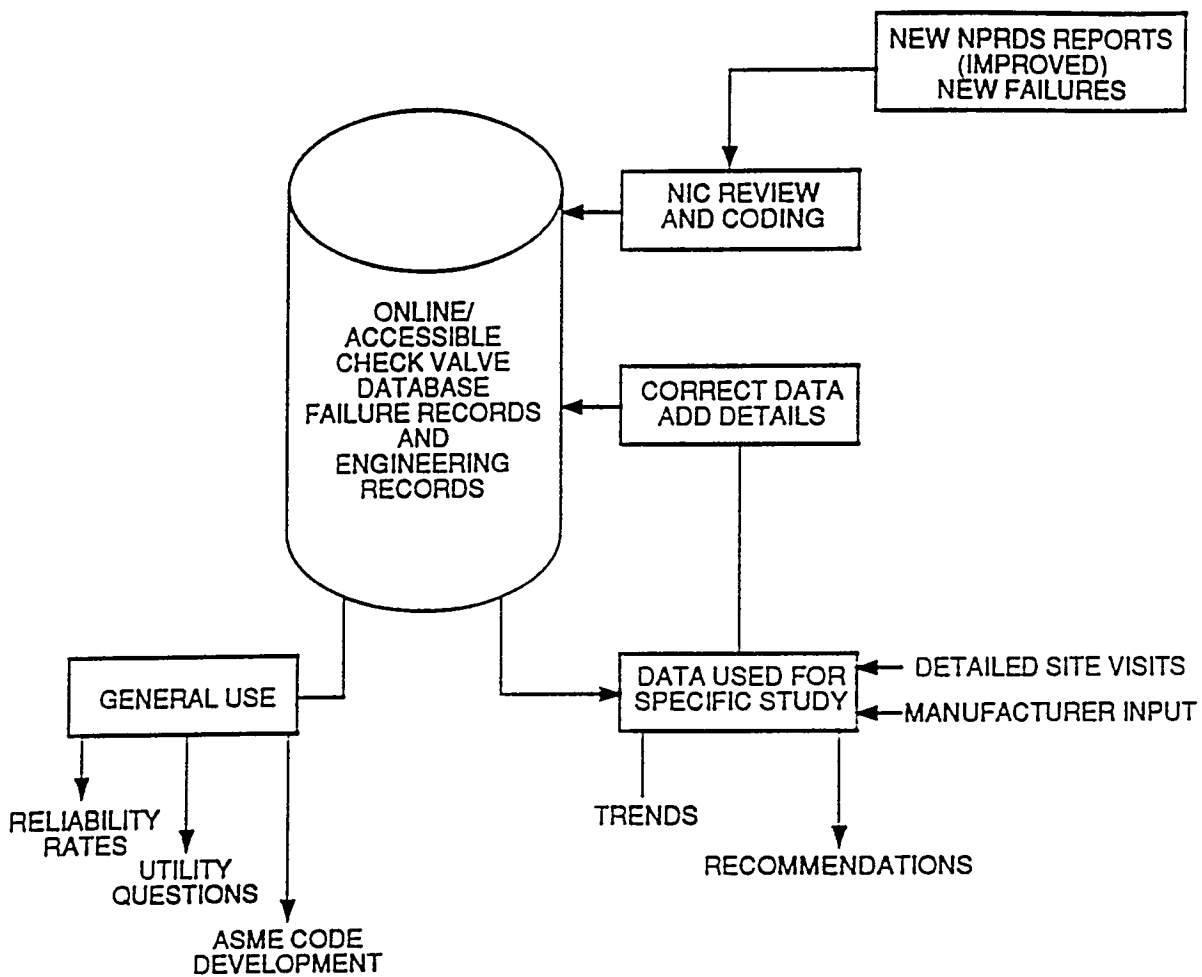
Check valves are critical components in the operation of nuclear power plants today and may serve an increasingly critical role in the designs of future advanced light water reactors (ALWRs). Check valve failures can result in significant operating transients, increased costs, and/or decreased system availability. Increasingly, the tools and methodologies which the industry uses to improve performance, monitor deterioration, and indicate improvement are based on component failure data. Such methodologies include the "maintenance rule" (10 CFR 50.65), which seeks to allow the industry to focus resources on problem areas based on system/component failure/availability indicators, "condition monitoring," a mechanism to utilize the best available information to determine the most appropriate means to monitor component operating condition, and probabilistic risk assessments (PRAs). Although existing failure data is available (with significant effort), it often fails to provide sufficient information for the check valve engineer to make educated decisions regarding his own applications. Most utilities have check valve engineers who possess an in-depth knowledge of the specific components at their facilities, but have limited knowledge of overall industry data available to address check valve issues. This makes it difficult for the engineer to take advantage of industry gains in the check valve arena and apply them to his facility.

It is essential that accessible, detailed failure data be made available to ensure that these methodologies are successful. Existing data must be reviewed, filtered, updated, and supplemented in order to provide the tools for successful implementation of proposed methodologies. Over the past several years the efforts of the Nuclear Regulatory Commission (NRC), Institute of Nuclear Power Operations (INPO), and the nuclear industry have laid a foundation and supplied the building blocks to establish a system to support these efforts. This system could be available in part by the end of 1994.

Recent studies<sup>1,2</sup> identified approximately 4000 check valve failures that occurred from 1984-1991. Of these, approximately 1600 were determined to be significant enough to require further analysis. This is to be compared with the existing check valve population of nearly 21,000 valves. The strategy proposed in this paper is to establish a refined, centralized check valve failure/reliability database based in part on existing INPO Nuclear Plant Reliability Data System (NPRDS) data. Ideally, the database would be maintained in a central location, augmented with specific component information, overall reliability information, and updated at least biannually. The conceptual plan is depicted in Fig. 1. Two key features required to maintain the database are

- (1) Independent review/coding of new failures as they occur (biannually), and
- (2) Ability to refine or add data based on detailed reviews of the failures and the linking of the failure data with other data sources, such as vendor design information and maintenance recommendations.

## CHECK VALVE FAILURE DATABASE CONCEPT



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The data would be available to sort and search as desired. Possible uses of the database would be to

- Provide support for individual valve applications/analyses/calculations,
- Provide supporting evidence for maintenance and condition monitoring programs,
- Support ASME Code development work,
- Provide detailed reliability data for future applications (e.g., ALWR designs), and
- Provide feedback to valve manufacturers on operating problems and failures.

## II. HISTORICAL EFFORTS

Uncoordinated reviews of check valve failures have been undertaken by numerous industry organizations and utilities over the past decade. Prior to recent research<sup>1</sup> performed by Oak Ridge National Laboratory (ORNL), one of the most recognized studies was the 1989 paper by M. L. Scott.<sup>3</sup> Scott reviewed NPRDS failure records for events occurring during the years 1985-1987. Events involving moderate seat leakage and external leakage were excluded from the study, and the remaining events analyzed. This study was originally slated for use by the ASME Committee on Operation and Maintenance (OM) of Nuclear Power Plants Working Group on Performance Testing of Check Valves in Light Water Reactor Power Plants (OM-22) as a basis for developing check valve performance test requirements. Although some questions later arose regarding the validity of the conclusions from the study, this study is recognized as being the first to address the historical failure analysis needed in code development activities.

Significant check valve failures occurring in the mid 1980s resulted in issue of the INPO Significant Operating Experience Report (SOER) 86-03, "Check Valve Failures or Degradation."<sup>4</sup> To address the discovery of deficient conditions pertaining to check valves, the NRC issued several notices, including Generic Letter 87-06, "Periodic Verification of Leak Tight Integrity of Pressure Isolation Valves,"<sup>5</sup> Information Notice 88-70, "Check Valve Inservice Testing Program Deficiencies,"<sup>6</sup> and Generic Letter 89-04, "Guidance on Developing Acceptable Inservice Testing Programs."<sup>7</sup> NUREG-1352, "Action Plans for Motor-Operated Valves and Check Valves"<sup>8</sup> was issued in June 1990. The activities outlined in this document included a discussion of check valve problems and performance, evaluation of adequacy of regulatory requirements, development of inspection guidance, research, cooperation with industry groups, development of codes and standards, and evaluation of NRC staff and industry efforts. The NRC also initiated a utility inspection program intended to evaluate check valve activities at each nuclear power plant.

In response to SOER 86-03, the Electric Power Research Institute (EPRI) reviewed the application and failure history of check valves, and published NP-5479, "Application Guide for Check Valves in Nuclear Power Plants," in 1986.<sup>9</sup> Their objective was to provide utilities with assistance in the areas of check valve applications, maintenance, and diagnostic techniques, and to provide technical guidance for prevention of premature valve failure and for assessing long-term reliability.

With the exception of the EPRI work which was revised in 1993,<sup>10</sup> none of the early efforts related to check valve reliability retained a measure of continuity. Each group independently evaluated the available failure data, analyzed it, and came to their own conclusions. Until the initiation of the ORNL study in 1992, no effort was undertaken to perform a comprehensive and consistent analysis of check valve failure data. During the OM-22 Working Group's consideration of the Scott paper and its application to code development, some concerns arose concerning the technical validity of the

Working Group's application of the study. As a result, ORNL was requested to conduct a preliminary review of failure data. Results of the preliminary review substantiated concerns about the use of the Working Group's basis study conclusions for use in code development activities. Accordingly, the NRC commissioned ORNL to conduct a more thorough assessment of the historical failure data.

NUREG/CR-5944 "A Characterization of Check Valve Degradation and Failure Experience in the Nuclear Power Industry" (reference 1) documents ORNL's evaluation of check valve failure data from 1984 through 1990. In addition to the report itself, a significant product from this effort was the failure database developed by reviewing the available NPRDS data, eliminating insignificant failures (i.e., those not involving internals degradation or those which exhibited only very minor seat leakage), and characterizing the remaining records according to failure mode, extent of degradation, detection method, and failure area. What resulted was a refined, usable database which may become the foundation for the proposed centralized failure/reliability database.

Attention may now be given to the process which developed this database and related efforts which are evolving within the nuclear industry to support continued efforts to expand this work.

### III. FOUNDATION FOR A CHECK VALVE DATABASE

#### III.A. Commitment of NRC and Nuclear Industry to the Effort

Support for the original ORNL evaluation of 1984-1990 failure data was provided by the NRC's Nuclear Plant Aging Research Program. Recognizing the need for a thorough assessment of check valve historical failure data, the NRC has committed to continue its support to ORNL to conduct updates on failure data for the years 1991 and 1992.

The Nuclear Industry Check Valve Group (NIC) has provided a focal point for the nuclear industry to become active in the failure data analysis. NIC's members have provided thoughtful review of the study methodology and failure characterizations, and have supplied additional information on failures not clearly explained in the NPRDS narratives. NIC cooperated with ORNL by providing detailed peer review of the data review process as well as by validation of the process with utility site visits. The site validation process involved 7 nuclear plants (12 units) in which site personnel used related maintenance work order packages and their knowledge of the failures to review the ORNL characterization of the NPRDS data. The conclusion of this validation process was that the ORNL study provided a fair and accurate assessment of the failures. Two limitations of the characterization process became apparent during the validation: (1) that the accuracy of the characterizations was dependent on the accuracy and thoroughness of the narratives, and (2) the reviewer must correctly interpret the narratives. Although it was noted that utilities had substantially improved the length and quality of narratives submitted to NPRDS during recent years, it would greatly enhance the accuracy and ease of use of the database if a means were provided to directly code in parameters such as the type of check valve and the affected (failure) area of the valve. Alternatively, if utility personnel responsible for submitting the failure records were made aware of the need to include such information in the narratives, the information could be obtained indirectly. Even though this approach would add to the effort required to evaluate the failure data, it would make the information available without modifying NPRDS.

### III.B. Improvements to NPRDS Coding Practices

Over the past several years, a significant improvement has been noted in NPRDS failure reporting as both INPO and the utilities have increased attention on the details reported within NPRDS. NPRDS reporting rules have been modified to eliminate requirements for reporting minor external leakage, etc., and also to require improvements in reporting practices. These changes should facilitate future attempts to retrieve and analyze failure data, since the initial filtering process necessary in past efforts should be performed at the plant level in the future. Also, improved reporting practices (i.e., narratives that more fully explain each failure, its root cause, failure area, corrective action, etc., as well as increased attention given to providing correct information in the engineering record) should eliminate the time consuming process of contacting plant personnel to request additional information.

### III.C. Additional Failure Data Review Efforts

Continuing the NRC commitment to this work, NIC formed a subcommittee in 1992 for "Industry Data Review." This subcommittee is undertaking detailed investigations on specific failure modes and systems identified in the ORNL analysis that exhibited high failure rates. NIC has already completed an in-depth study of failures with a "stuck closed" failure mode (see Appendix A), and plans to initiate data reviews on other specific cases.

### III.D. Ongoing Efforts (1991 NPRDS Failure Data Analysis)

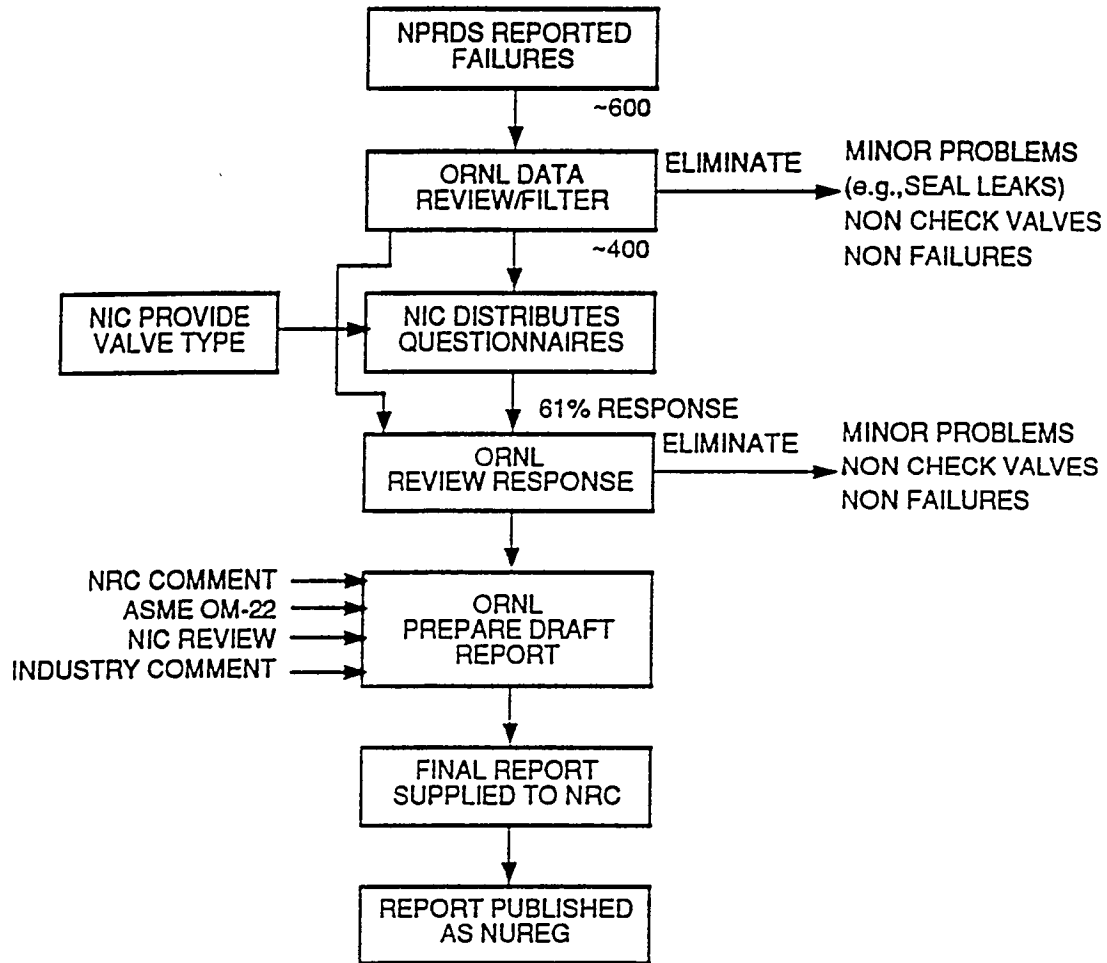
In an effort to continue their initial work, ORNL began a review of the 1991 NPRDS check valve failure data in June 1993. During the Summer NIC meeting of that year, a revised methodology was developed for the 1991 study based on lessons learned from the original ORNL review of 1984-1990 data, the site validation effort, and a desire to support current issues being raised by the OM-22 Working Group. In order to acquire additional information not available in NPRDS records, the NIC subcommittee on Industry Data Review formulated a questionnaire to be sent to each affected site. Information requested on the questionnaire included specific valve type, special design features, configuration, application, inclusion in site check valve program(s), and other design data intended for NIC use only. Questionnaires were mailed out in August, and follow-up phone calls were made in October and December. Approximately 61% of the plants responded to the survey. Some information requested but not received was obtained through vendor catalog and EPRI check valve database review. Improved NPRDS failure narratives and questionnaire results provided a means for significant improvement of the failure database for 1991, and it is hoped that this type of information can be obtained for the already existing 1984-1990 database as well as for the proposed centralized failure/reliability database. Figure 2 illustrates the process used to perform the 1991 analysis, and Appendix B discusses the preliminary results.

## IV. VISION FOR A CHECK VALVE DATABASE

### IV.A. Lessons Learned

Both historical and current efforts have identified deficiencies in failure reporting requirements and practices. From working with data available from NRPDS, certain specific weaknesses have been discovered. These weaknesses include:

## CHECK VALVE FAILURE DATA REVIEW PROCESS FOR 1991



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- (1) The specific type of check valve (e.g., swing, lift, tilting disc) is not captured in either the NPRDS engineering record or the failure report.
- (2) Failure narratives often omit specific details concerning root cause, affected valve area, application, discovery method, failure mode, corrective action, etc.
- (3) Program status is difficult to determine (e.g., Inservice Testing (IST), 86-03, preventive maintenance program).

Since past analysis attempts have been hindered by lack of certain information such as specific valve type, these fields were added to the questionnaire sent to affected utilities for the 1991 data. Most of the information requested on the 1991 questionnaire is as yet unavailable for the 1984-1990 data and the overall valve population, however it is anticipated that the procedure developed by NIC in conjunction with EPRI to gather data (e.g., specific valve type) for those plants not responding to the 1991 questionnaire can be used to address these deficiencies. This process normally involves the use of the NPRDS fields of Manufacturer Name, Manufacturer Model No., Model ID, Size, and Drawing No. to identify the specific valve type from manufacturer catalogs and the EPRI check valve database.

#### IV.B. Future Efforts

##### IV.B.1 Specific Case Reviews

It has been demonstrated that full benefit can be obtained from the existing failure database by undertaking specific case reviews, such as the "stuck closed" failure mode review. NIC plans to continue specific data reviews concurrently with the annual NPRDS data review updates so that results obtained may be incorporated into the annual reports. It is anticipated that the results of such reviews may be of direct and immediate use to the nuclear industry, and will enhance the overall usefulness of the failure data analysis. As these benefits become apparent to utilities, it is hoped that increased emphasis at the site level will be placed on ensuring that the information needed to perform the detailed case reviews is input into NPRDS at the time of the failure. NIC currently has plans to initiate specific case reviews on check valve failures in Diesel Starting Air systems as well as those where the valve disc or other parts have broken or become detached.

##### IV.B.2 NPRDS Data Review Updates

Tentative schedules for future NPRDS failure data updates were developed at the Winter 1993 NIC meeting. The schedules for these reviews are listed below:

##### 1991 NPRDS DATA REVIEW

- 2/94 Utility questionnaires complete
- 5/94 Data compiled; draft report available
- 6/94 Industry review of draft report at Summer NIC meeting
- 12/94 Final NUREG issued

## 1992 NPRDS DATA REVIEW

5/94 1992 failure data downloaded; begin initial screening  
7/94 Questionnaires distributed  
5/95 Data compiled; draft report available  
6/95 Industry review of draft report at Summer NIC meeting  
12/95 Final NUREG issued

## 1993 NPRDS DATA REVIEW

5/95 1993 failure data downloaded; begin initial screening  
7/95 Questionnaires distributed  
5/96 Data compiled; draft report available  
6/96 Industry review of draft report at Summer NIC meeting  
12/96 Final report issued

### IV.B.3 NPRDS Enhancements

Based on lessons learned from NPRDS failure data reviews, a listing of desired information to be made available in either the NPRDS engineering record or failure record for each valve has been formulated. NIC has initiated discussions with INPO in an attempt to upgrade the NPRDS database itself. NIC also plans to contact cognizant check valve engineers at each utility to encourage them to work with their NPRDS reporter in order to improve the information included in each NPRDS report. Table 1 is a list of NPRDS enhancements proposed by NIC at their Winter 1993 meeting (the last four items are already in use, however, utilities need to ensure that they are used properly). It is hoped that revisions currently in process to NPRDS may accomplish these enhancements:

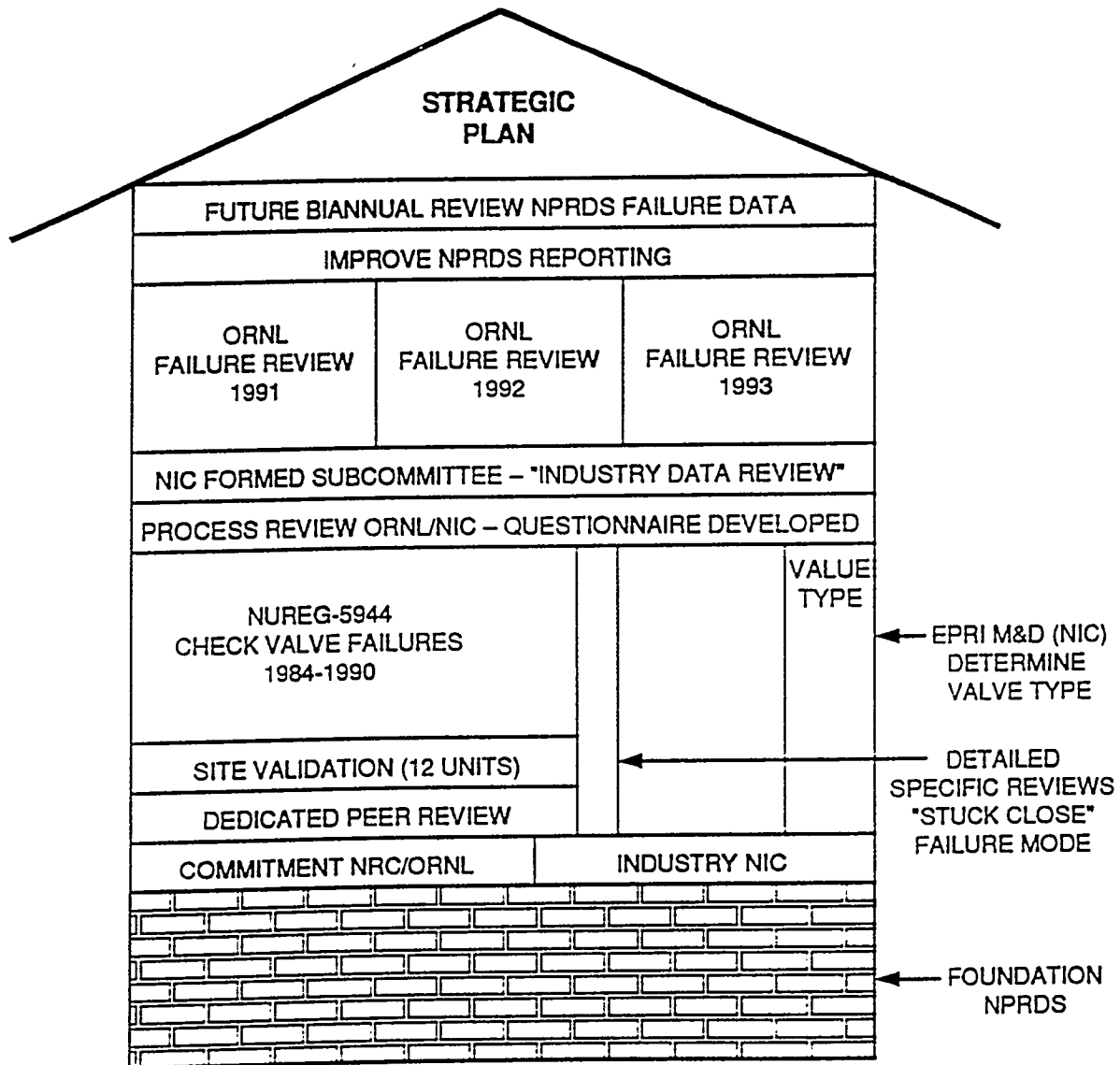
### IV.B.4 Strategic Plan

In order to establish the proposed centralized failure/reliability database, a strategic plan must be developed. This plan must address the issues of

- Procedures for data control and update,
- Responsibility for operation and maintenance of the database,
- Ability to add new data fields and support future efforts,
- Database access, and
- Review and coding of new data.

NPRDS reporting practices must also be enhanced to incorporate the needs of this and potentially similar databases as well as to improve the efficiency and cost for future updates. Figure 3 illustrates the "building blocks" necessary to develop such a database.

## BUILDING BLOCKS FOR A CHECK VALVE DATABASE



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Table 1. NIC Proposed NPRDS Enhancements

| DATA FIELD                 | IMPORTANCE                  | ENGINEERING RECORD | FAILURE RECORD |
|----------------------------|-----------------------------|--------------------|----------------|
| VALVE TYPE                 | Needed                      | X                  |                |
| VALVE TYPE DETAILS         | Desired                     | X                  |                |
| DESIGN FEATURES            | Desired                     | X                  |                |
| FAILURE AREA               | Found in description        |                    | X              |
| INSTALLATION CONFIGURATION | Low                         | X                  |                |
| APPLICATION                | Low<br>(some already coded) | X                  |                |
| PROGRAM                    | Desired                     | X                  |                |
| ROOT CAUSE                 | Already coded               |                    | X              |
| REPETITIVE FAILURE?        | Already coded               |                    | X              |
| MODIFICATION INVOLVED?     | Already coded               |                    | X              |
| DESIGN PROBLEM?            | Already coded               |                    | X              |

## V. CONCLUSION

Although the check valve failure database developed from ORNL review of NPRDS failure records has some limitations, it has been used successfully to produce cross-correlations and analysis data unavailable from past analysis efforts. The database has also been used successfully as a basis to initiate specific case studies, as exemplified by the "stuck closed" valve study. Ideally, however, in order to exploit its full usefulness, such a database should be upgraded and supplemented to provide both specific valve failure information and overall reliability information for any valve type, manufacturer, operating environment, configuration and other parameters. This database would be maintained in a centralized location and updated at least biannually. The database would be accessible to any check valve engineer at any site, the NRC, valve manufacturers and other related vendors (with some limitations), and would provide a mechanism to allow the implementation of tools and methodologies using component failure data as their basis.

Since the current population of check valves in use in nuclear power plants is relatively small, the proposed check valve database is believed to be a manageable effort. If efforts to establish such a database are successful, extension to other types of valves and components is logical. Perhaps the next logical step would be to establish a failure database for motor operated valves (MOVs) or air operated valves (AOVs), with progressions to pumps, motors, etc.

## REFERENCES

1. NUREG/CR-5944, "A Characterization of Check Valve Degradation and Failure Experience in the Nuclear Power Industry," U.S. Nuclear Regulatory Commission, 9/93.
2. "A Characterization of Check Valve Degradation and Failure Experience in the Nuclear Power Industry, 1991 Update," Draft Report.
3. M.L. Scott, "Check Valve Failure Trends in the Nuclear Industry," EPRI Power Plant Valves Symposium II, Charlotte, N.C., July 1989.
4. INPO SOER 86-03, "Check Valve Failures or Degradation," Institute for Nuclear Power Operations, 10/15/86.
5. Generic Letter 87-06, "Periodic Verification of Leak Tight Integrity of Pressure Isolation Valves," U.S. Nuclear Regulatory Commission, issued 3/13/87.
6. Information Notice 88-70, "Check Valve Inservice Testing Program Deficiencies," U.S. Nuclear Regulatory Commission, issued 8/29/88.
7. Generic Letter 89-04, "Guidance on Developing Acceptable Inservice Testing Programs," U.S. Nuclear Regulatory Commission, issued 4/3/89.
8. NUREG-1352, "Action Plans for Motor-Operated Valves and Check Valves," T.G. Scarbrough, U.S. Nuclear Regulatory Commission, 6/30/90.
9. EPRI NP-5479, "Application Guidelines for Check Valves in Nuclear Power Plants," prepared by MPR Associates, Inc. and Kalsi Engineering, Inc. for Electric Power Research Institute, Palo Alto, California, 12/90.
10. EPRI NP-5479R1, "Application Guidelines for Check Valves in Nuclear Power Plants," prepared and edited by Douglas E. MacDonald for Electric Power Research Institute, Nuclear Maintenance Applications Center, Charlotte, North Carolina, 4/93.

## APPENDIX A - STUCK CLOSED CHECK VALVE STUDY

### A.I. INTRODUCTION

In December 1992, the Nuclear Industry Check Valve Group (NIC) subcommittee on Industry Data Review initiated a task to analyze in detail all failures identified in the 1984-1990 analysis<sup>1</sup> having a failure mode of "stuck closed." This group of failures was selected for further analysis for several reasons:

- All events characterized as having a stuck closed failure mode were classified as severe.
- A manageable number of failures was reported (83 out of 1227 events analyzed in NUREG/CR-5944 were characterized as stuck closed).
- This failure mode represents one of the most detrimental conditions (e.g., failure of a check valve to open could defeat a train or system function).

### A.II. PURPOSE OF REVIEW

The purpose of the review was multifold:

- To understand in detail the failure modes, failure population, and root causes for this important block of failures,
- To determine the feasibility and functionality of data review and analysis at a detailed level,
- To identify methodology or data problems which would hinder an analysis at a detailed level,
- To produce concrete, supportable conclusions and recommendations to demonstrate the significance of a detailed review and analysis,
- To provide conclusions which would support improved check valve program development. I.e.,
  - Identify factors which may result in increased failures,
  - Identify "good actors,"
  - Identify specific factors/situations which demonstrate increased failures, and
- To provide the foundation for establishing rules and guidelines for future reviews to ensure required uniformity and control (to allow for data combination/cross reference).

### A.III. METHODOLOGY

The basis for the review of the stuck closed events was NUREG/CR-5944, "A Characterization of Check Valve Degradation and Failure Experience in the Nuclear Power Industry." This study classified all significant failures (i.e., those involving internals degradation) reported in the Institute of Nuclear Power Operation (INPO) Nuclear Plant Reliability Data System (NPRDS) during the analysis period of 1984-1990 according to failure mode (among other parameters). The "stuck closed" failure mode was described in the NUREG as "Valve will not open when forward pressure is applied."

At the 1992 Winter NIC meeting, the Industry Data Review subcommittee reviewed the preliminary NUREG data in order to determine the additional information that would be required for check valve experts to perform a detailed review of the stuck closed failures. A "detailed review" is defined as a review of each individual failure to obtain as much information as possible about that failure and its relationship to similar failures. Based on their review, questionnaires were sent to the 37 utilities that reported the stuck closed failures. Specific additional information requested was:

- Confirmation of failure,
- Specific valve type (e.g., swing, lift, tilting disc),
- Stem/hinge penetration,
- Valve application,
- Site program(s) that valve was included in (e.g., Inservice Testing (IST) program, 86-03 program, Preventive Maintenance (PM) program), and
- Details of failure discovery.

Approximately one-third of the utilities initially responded to the survey. A preliminary summary of the data was provided at the Summer NIC meeting in June 1993. Individual NIC members contributed additional data and NIC solicited all remaining utilities to provide their input. The remaining information was gathered prior to the Winter NIC meeting in December 1993.

Supplemental data gathered from the utilities was linked to the original NUREG data using a relational database. Evaluations were based on the combined data of the two efforts.

#### A.IV. RESULTS

It was determined that 15 of the 83 reported failures (18%) initially characterized as "stuck closed" were not legitimate stuck closed check valve failures (i.e., the valve was not a check valve or the valve did not actually stick closed, etc.). Therefore, the actual analysis involved the 68 remaining failures.

##### A.IV.a. Site Valve Programs

As the scope of NPRDS varies from site to site, so do PM programs, response to INPO Significant Operating Experience Report (SOER) 86-03, etc. Some check valves reported as having failed were not included in any site valve program at the time of failure, while others were included in one or more site programs. The program status of the original 83 check valves is presented in Fig. A-1. Twenty-one percent of the 83 valves were either in no program or had an unknown program status. Eighteen percent of the original failures were determined to be invalid for the purposes of this study, while 12% were included in the site 86-03 program, and 42% were included in the IST program. Seven percent of the valves were included in both 86-03 and IST programs.

To measure the effectiveness of the various valve programs, some factors must be considered in greater detail. The analyst must ideally know:

What program(s) the check valve was included in, and

Whether the failure was identified as a result of the program(s).

This study could not determine the effectiveness of the site valve programs. To make this determination, an additional valve population study would be required. Using a population study and assuming a relationship between plant system and valve program(s), some conclusions might be attempted.

#### A.IV.b. Valve Age

Since the number of valves included in this study was small and the other factors affecting the failure mode were thought to be more significant (e.g., specific valve type, application), a review of age effects was not considered for the total population but rather individually by specific valve type.

#### A.IV.c. Specific Check Valve Type

Initial discussions by the NIC subcommittee on data review identified the importance of basing a detailed review on specific check valve type. This information was determined to be essential to a detailed analysis since it was believed that failure mechanisms should vary with valve type. For example, while sticking closed was thought to be a valid failure mode for lift check valves, it was difficult for the subcommittee to imagine the mechanism required to stick a simple swing check valve shut.

The results of the review of the 68 valid stuck closed failures are depicted in Fig. A-2. As theorized, two factors were apparent from the results:

- (1) Lift/piston type check valves are much more prone to failing by sticking closed than were either tilting disc or swing check valves, and
- (2) Twenty-three failures were vacuum breaker valves which failed to open at a precise set pressure.

#### A.IV.d. Lift/Piston Check Valves

Sixty percent (41) of the 68 valid stuck closed failures involved lift/piston type check valves. This is thought to be largely due to the tight clearances inherent between the disc and the body or body guides of these types of valves. The material composition of the valve can increase such an effect. Carbon steel can rust and pit and is susceptible to bacterial growth and biological fouling which can lead to binding of internal components. Table A-1 shows that the carbon steel valves had more failures and a shorter life than did the stainless steel valves (although it must be recognized that this data is not normalized; i.e., population effects were not considered for this analysis, and may have a significant effect, once determined).

Table A-1 Lift/Piston Check Valves- Material Comparison

| Material        | No. of Valves* | Age to Failure (yrs.) |
|-----------------|----------------|-----------------------|
| Carbon steel    | 35             | 1-19                  |
| Stainless steel | 5              | >16                   |
| Other           | 1              | 21                    |

\*Including vacuum breakers

General causes of failure were attributed to dirt, rust, and crud buildup. It appears that the use of lift/piston check valves in raw water systems increases the probability that binding will occur, since even small particles can jam or stick in the area between the disc and body and prevent movement. A review of some vendor manuals pointed out that this potential does indeed exist. (It should be noted that typically, use of stainless steel valves is not considered for these systems, due to cost considerations.)

Utilities were able to mitigate problems with these types of valves by increasing inspection intervals and by modifications which either eliminated the valve, upgraded the material (to stainless steel), or changed the valve type. Few repeat failures were noted over the study's time period (1984-1990).

#### A.IV.e. Swing Check Valves

Only six failures of swing check valves were reported during the NUREG analysis period (excluding thirteen vacuum breaker failures). It was attempted to analyze each failure in detail:

Table A-2 Swing Check Valve Failures

| No. of Valves | Size (in.) | Cause of Failure                                                                                                                       | Corrective Action                                                                           |
|---------------|------------|----------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|
| 1             | 3/4        | Poor design.                                                                                                                           | Replace valve.                                                                              |
| 2             | 2          | Welded bonnet design prevented normal maintenance.                                                                                     | Remove internals.                                                                           |
| 1             | 10         | No failure cause reported.<br>Failure detected by IST program.                                                                         | Not given.                                                                                  |
| 1             | 20         | Insulation interfered with external arm.                                                                                               | Modify valve to ensure proper clearance.                                                    |
| 1             | 24         | Mission type valve out of service for extended period (>6 months) in raw water system. Valve found packed with mud and unable to open. | Program changes instituted to ensure that valve is flushed every 90 days if not in service. |

The decreased susceptibility of the swing check valves (compared to other types of check valves) to stuck closed failure is demonstrated by their age to failure, which occurred between 9-17 years. The mean age to failure was 14 years. No failure was reported prior to nine years of service. Five out of the six failures of swing check valves were on carbon steel valves.

#### A.IV.f. Tilting Disc Check Valves

The tilting disc design is in some ways similar to the swing check design. Its failure performance also appears to be similar. Seven of eight failures involving tilting disc valves were on carbon steel valves. The mean age to failure was 13 years with a range from 9 to 17 years.

Five tilting disc valve failures involved valves which were considered of low safety importance and were not included in any site valve program. The utility considered it acceptable practice to operate these valves until failure.

Another five tilting disc valve failures involved valves built by the same manufacturer whose design incorporates two features possibly contributing to the failures:

- (1) A split body design on a 45° angle which could cause a pinching effect, and
- (2) Angled seats, which if closed under high pressures could jam shut.

A unique hinge pin lubrication system and a potential for extremely tight clearances combined with unusually hard bushing/pin material may have contributed to the stuck closed failures of these tilting disc valves. It appeared that further discussions with the valve manufacturer were warranted.

#### A.IV.g. Vacuum Breaker Valves

Of the 41 reported stuck closed failures involving lift/piston check valves, 10 were vacuum breaker valves. These valves had a mean life of nine years and a range to failure from six to fourteen years. Of the ten failed valves, nine were subsequently modified to improve performance. The most common modification was the removal of the spring to allow for easier opening.

Of the 19 failures involving swing check valves, 13 were vacuum breaker valves. These valves had a mean life of four years and a range to failure of one to seven years. Of the 13 valves, 12 were at the same plant and are scheduled for modifications to allow for easier opening. Stroking frequency was increased to once every six months for the other valve in order to eliminate binding.

Typically, vacuum breaker failures were failures of the valve to open at a prescribed setpoint. In some cases, the valve was required to open at as little as 25 inch-pounds of torque. In a sense, this type of failure is more of a setpoint problem, more typical of safety relief valves (SRVs) than of other check valves. The "Extent of Degradation"<sup>1</sup> classification of "severe" may also not be warranted in that in the cases reported, the valve would have been able to open and allow flow, but at a reduced level or slightly higher pressure. Since this failure mode is not representative of check valves as a group, consideration should be given to grouping vacuum breaker failures separately.

## A.V. CONCLUSIONS AND RECOMMENDATIONS

An analysis of check valve failures with a failure mode of "stuck closed" revealed that:

Detailed reviews are feasible and can be performed with a minimum of effort (assuming utility cooperation).

Information can be assembled and conclusions reached that can be used to support improved utility check valve programs, i.e., identification of factors which may contribute to increased failure rates, assist in valve application, testing frequencies, etc.

Problems can be identified which may impede future detailed reviews and analyses.

Population effects (i.e., data normalization) must be considered when analyzing data for specific conclusions.

Such activities may be used to develop a standard methodology.

Specific conclusions from the study include:

Check valves are not particularly susceptible to "stuck closed" failures (only 83 out of 1227 [7%] of the failures analyzed from 1984-1990 involved this failure mode).

Of the 83 failures analyzed in detail, only 68 were determined to be valid stuck closed failures. Of these, lift/piston type check valves were the most susceptible to failure due to sticking or binding caused by rust, dirt, and crud accumulation. Twenty-three of the 83 failures (28%) involved vacuum breaker valves failing to open at a precise set pressure.

Sticking closed is a very low probability failure mode for simple swing type check valves.

Age to failure is significant for swing or tilting-disc type check valves (> 9 years).

Utilities have made a concerted effort to improve reliability of valves which have failed stuck closed.

Problems with the data review were encountered with getting utilities to respond to requests for information and insufficient information (e.g., which valves were included in site valve programs, whether failures were discovered as a result of the programs, etc.).

Specific recommendations resulting from this review are discussed below:

It is recommended that due to their design differences from typical check valves, vacuum breaker valves be considered as a separate classification. These valves were involved in over one-third of the valid stuck closed cases. Typically, they were not "stuck closed" in the sense that the valve would not open under normal operating conditions, but rather that they failed to open at a prescribed setpoint under test conditions. The failure mode of vacuum breaker valves appears to be similar to that of SRVs.

Lift/piston check valve applications in dirty or stagnate systems should be reviewed by individual utilities in order to assess their susceptibility to sticking closed. Measures to mitigate the potential for failure may include:

- Flushing,
- Valve Replacement,
- Increased review/analysis,
- Increased testing,
- Vendor-specific review, and
- Cleanup of dirty systems.

Additional review of tilting-disc type valves with a split body design may be warranted. Evidence suggests that this design may be particularly susceptible to sticking closed due to its 45° angle which could cause a pinching effect, and angled seats, which if closed under high pressures could jam shut. A unique hinge pin lubrication system and a potential for extremely tight clearances combined with unusually hard bushing/pin material may have contributed to the stuck closed failures of these tilting disc valves.

Final recommendations are to develop a methodology for detailed failure review and standardize the approach to and presentation of failure data, and to continue the analysis of stuck closed failures based on data available from annual NUREG updates.

## APPENDIX B - ANALYSIS OF 1991 NPRDS FAILURE DATA

### B.I. INTRODUCTION

In order to provide a thorough assessment of historical check valve failure experience, the NRC committed to continue its support to ORNL to conduct updates on failure data for the years 1991 and 1992. Accordingly, ORNL initiated a review of the NPRDS failure data for 1991 in May of 1993. The process followed was consistent with that used for the 1984-1990 analysis,<sup>1</sup> but was supplemented with information obtained directly from utilities. This additional information included specific valve type, detailed failure narratives, valve orientation, proximity to upstream disturbances, whether the failure was due in part to design, and an assessment of ORNL-characterized parameters such as failure area, failure mode, severity of failure, etc. This utility input provided not only supplemental information not available from NPRDS, but also an increased level of confidence in the quality of data utilized in the failure analysis. Information was entered into a failure database, and combined with the NPRDS check valve population database, was used to conduct an analysis of check valve failures for 1991.

### B.II. RESULTS

Since the NRC is primarily interested in trending of industry performance, the effort focused on comparison of results of the 1991 analysis with that of the 1984-1990 study. This appendix discusses significant trends identified from the analysis. It also presents a look at additional findings related to specific valve type (data which was not available in the previous analysis), information which is especially important to performance of detailed check valve failure analyses. (It should be noted that since the results of the 1991 analysis have not yet been published, data presented herein should be considered preliminary.)

Fig. A-1 shows that of the 401 failures included in the 1991 study, 76% were discovered programmatically. A "programmatic" discovery process refers to failure discovery during the conduct of a surveillance test, inservice inspection or test, leak rate test, or during another type of test or periodic preventive maintenance. Non-programmatic discovery methods include routine or incidental observation, abnormal equipment operation, special inspection, or where the discovery method was unclear. Compared with only 54% of the 1984-1990 failures discovered by programmatic means, this represents a significant positive trend toward controlled check valve performance evaluation and failure detection.

Fig. A-2 illustrates the failure distribution by extent of degradation, defined for purposes of this analysis as either moderate or significant. "Moderate" failures include failure of the valve to seat properly, moderate internal leakage, loose internal assembly (without attendant problems, such as stuck open), or a miscellaneous failure in which the level of degradation was not evident from the failure narrative. "Significant" failures include those with broken and/or detached internals, restricted motion, stuck open and stuck closed cases, cases where valves failed to open at set pressure, and excessive internal leakage. It should be noted that only 36% of the 1991 failures were classified as significant, compared to 53% in 1984-1990.

Failure distribution by failure mode is shown in Fig. A-3. Another positive trend is evident here, and is related to the number of significant versus moderate failures. Failures due to improper seating increased from 45% in 1984-1990 to 63% in 1991 (moderate failures), while those attributed to significant failures declined. For example, stuck open failures dropped from 28% to 11% of the total number of failures, disc/other part off or broken fell from 10% to 4% of the total, and stuck closed decreased from 7% to 4% of the total number of failures. Only slight increases were noted in the percentages of failures attributed to loose/damaged part (from 2% to 5%).

Fig. A-4 shows the relative failure rate by system, for systems with the highest failure rates. It can be seen that Containment Isolation, Diesel Starting Air, and Suppression Pool Support had the highest relative failure rates for 1991. Emergency Service Water (ESW), Feedwater, and Diesel Starting Air had the highest relative failure rates for 1984-1990. Note that ESW dropped to twelfth place while Feedwater fell to fourth place in the 1991 analysis. Only systems with 100 or more valves were considered for the 1991 analysis, and data presented is normalized using the procedure developed for the 1984-1990 analysis. This procedure involves determination of an overall failure rate for all check valves (for 1991), and application of this value to the individual category failure rates to determine the "Relative Failure Rate."<sup>1</sup>

Failure distribution according to specific valve type is presented in Fig. A-5. Information for this chart was obtained primarily from utilities who responded to a questionnaire developed and distributed by NIC for the 1991 analysis. Additional information was obtained from manufacturer catalogs and the EPRI check valve database. It can be seen that failures are nearly evenly divided between lift checks and swing checks (34% and 33% of the total failures, respectively), while 10% were tilting-disc valves, 5% were duo/double disc, and 2% or less of stop checks, in-line checks, and other types of check valves. Only 12% of the valves represented in the 1991 failure analysis could not be identified according to their specific type. It should be pointed out that this information cannot be compared to the check valve population for purposes of normalization, since specific valve type information is not yet available for the population database. It is intended that this study become the groundwork for future efforts, including establishment of the proposed centralized failure/reliability database.

Fig. A-6 is an example of presentation of data previously unavailable before the 1991 analysis. Fig. A-6 depicts failure distribution by specific valve type and failure mode. From this, for example, it can be seen without further detailed analysis that no failures of swing check valves were reported in 1991 with a failure mode of stuck closed, while approximately one-tenth of the lift check valve failures were attributed to this mode. It is also obvious that regardless of valve type, the greatest fraction of failures was attributable to improper seating.

### B.III. CONCLUSIONS

From the summary of preliminary results of 1991 NPRDS check valve failures analyzed by ORNL, it is apparent that a positive trend exists regarding general discovery process (i.e., programmatic versus nonprogrammatic), extent of degradation, and failure mode. A more detailed analysis is underway, and will be presented in the NUREG which updates NUREG/CR-5944 for the 1984-1990 analysis. Approximately 88% of the valves included in the 1991 analysis were classified according to their specific valve type, and using this information, more detailed analyses can be performed than from prior data. It is anticipated that this type of data will again be requested from the utilities for the 1992 update, and will be used to form the basis for the proposed failure/reliability database.

Figure A-1 Distribution of Failures by General Discovery Process  
(values in parentheses are results of the 1984-1990 study)

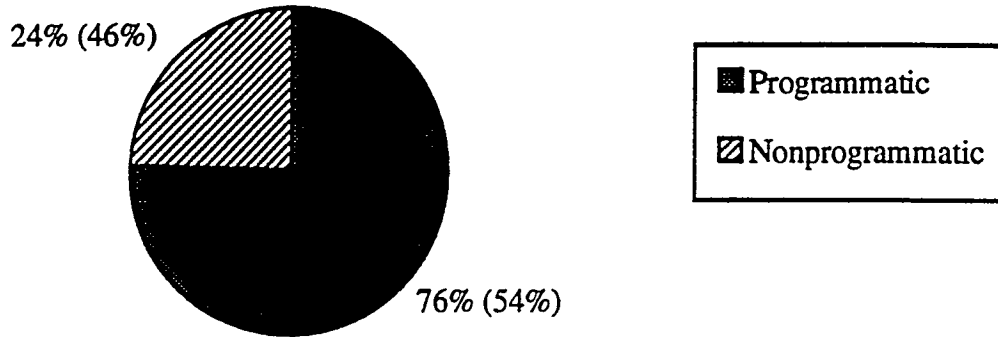


Figure A-2 Distribution of Failures by Extent of Degradation  
(values in parentheses are results of the 1984-1990 study)

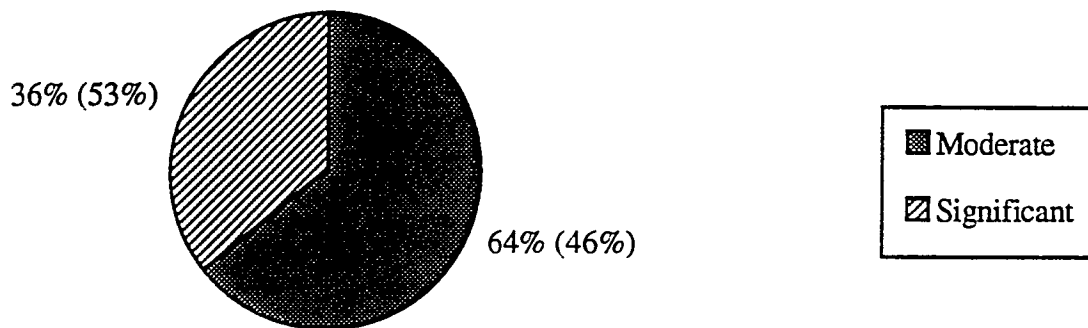


Figure A-3 Distribution of Failures by Failure Mode  
(values in parentheses are results of the 1984-1990 study)

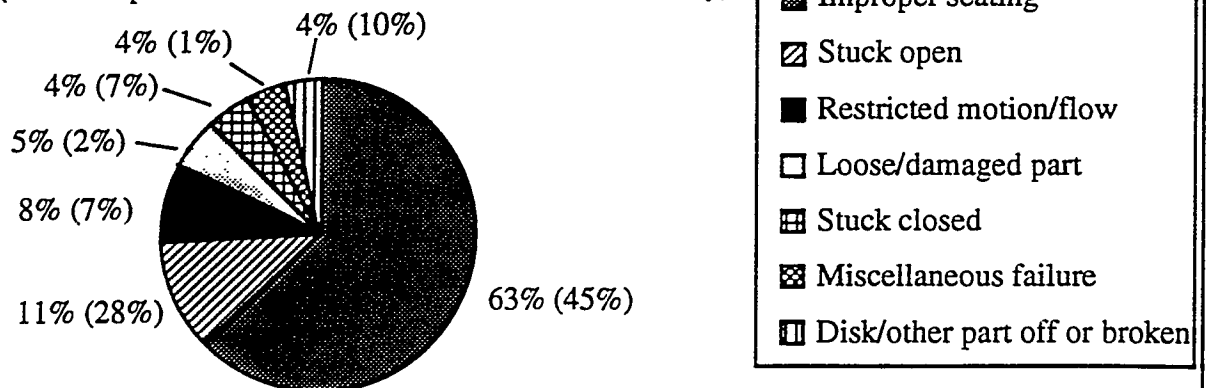


Figure A-4 Relative Failure Rate by System for Systems with the Highest Failure Rates

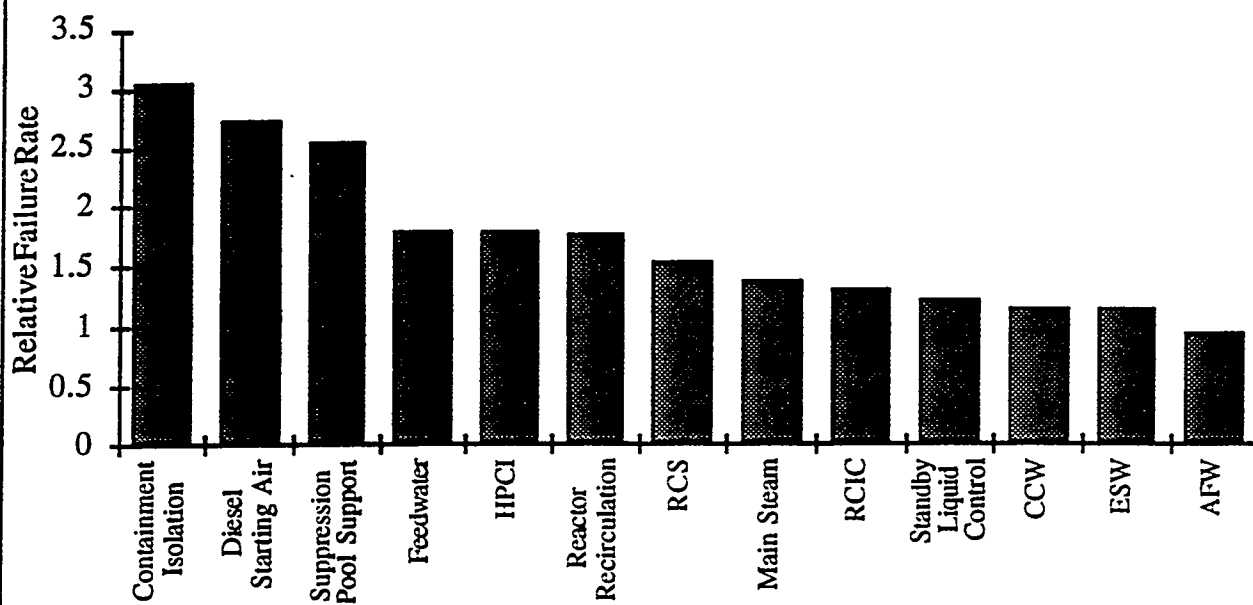


Figure A-5 Distribution of Failures by Specific Valve Type

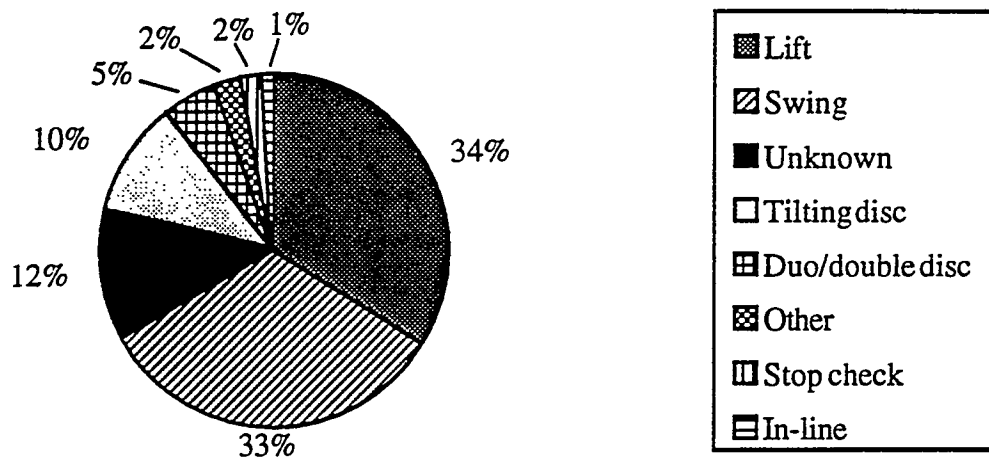


Figure A-6 Distribution of Failures by Specific Valve Type and Failure Mode

